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A Hybrid Grid Connected PV Battery Energy Storage System with Power Quality Improvement



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Abstract:

This paper presents the micro-grid integration with photo voltaic generation with the following intelligent functionality to feed generator active power and to compensate reactive power, load balancing, and reduction of harmonics, improving efficiency and power factor by using maximum power point technique. A Battery Energy Storage System (BESS) is employed to balance the power between Photo Voltaic generation and grid utility.

Grid integration of photo voltaic (PV)/Battery hybrid energy conversion system with (i) MPPT tracking performance of high gain integrated cascaded boost (HGICB) dc-dc Converter with quadratic gain and less current ripple, (ii) tight voltage regulation capability of battery converter (iii) multi-functional features of micro grid-side bidirectional voltage source converter.

A model of this hybrid system is developed in MATLAB/SIMULINK environment to test the dynamic performance of battery converter is investigated. The simulation results under a unbalanced non-linear load with current THD of 12% confirm that the μG- VSC can effectively inject the generated active power along with power quality improvement features.

Index Terms:

PV energy conversion system, high gain integrated cascaded boost dc-dc converter, instantaneous symmetrical components theory, battery energy storage system.

The usage of the renewable energy sources is increasing day to day due to the non availability of excessive fuel energy sources. Among various renewable energy sources solar energy and wind power are most rapidly growing renewable sources.

With increasing load demand and global warming, many are looking at environment-friendly type of energy solutions to preserve the earth for the future generations. Other than hydro power, many such energy sources like wind and photovoltaic energy holds the most potential to meet our energy demands. While some others like fuel cells are in their advanced developmental stage. The world's fastest growing energy resources, a clean and effective modern technology that provides a hope for a future based on sustainable, pollution free technology.

Today's photovoltaic and wind turbines are state-of-the-art of modern technology-modular and very quick to install. These generation systems have been attracted greatly all over the world. The integration of renewable energy sources and energy-storage systems has been one of the new trends in power-electronic technology. The increasing number of renewable energy sources requires new strategies for their operations in order to maintain or improve the power-supply stability, quality and reliability.

There are some previous works on hybrid systems comprising of wind energy, photovoltaic and fuel cell have been discussed. A maximum power point tracking (MPPT) is discussed on photovoltaic energies. Dynamic Modeling and Control of a Grid-Connected Hybrid Generation System was analyzed.

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Dynamic performance of a stand-alone wind and solar system with battery storage was analyzed. A few systems consider the battery as just a back-up means to use when there is insufficient supply from renewable sources. This paper focused on system engineering, such as maximum power production, system stability and reliability and reduction in the total harmonic distortion. All the energy sources are modeled using MATLAB software tool to analyze their behavior. A simple control method tracks the maximum power from the solar energy source to achieve much higher generating capacity factors. The simulation results prove the feasibility and reliability of this proposed system.

Micro-grid power converters can be classified into three types (i) grid-feeding,
(ii) grid-supporting, and (iii) grid-forming power converters. There are many control schemes that are reported in the literature such as synchronous reference theory, power balance theory, and the DC vector control, for control of µG-VSC in micro grid application. These algorithms require complex coordinate transformations, which is cumbersome. Compared to the control strategies mentioned above, the Instantaneous symmetrical component based control proposed in this paper for micro-grid applications is simple in formulation, avoids interpretation of instantaneous reactive power and needs no complex transformations. This paper is structured as follows: In section II, the system description and the modeling of various components are presented. The Maximum power point tracking is discussed in section III. The proposed control strategies for HGICB DC-DC Converter, Battery Converter and µG-VSC are discussed in section IV. The simulation results are presented in the section V. Concluding remarks in section VI.

II. SYSTEM DESCRIPTION:

The envisaged system consists of a PV/Battery hybrid system with the main grid connecting to non-linear and unbalanced loads at the Point of Common Coupling as shown in the Fig. 1. The photovoltaic system is modeled as nonlinear voltage sources. The PV array is connected to HGICB dc-dc converter and bidirectional battery converter is shown in Fig. 1, which are coupled at the dc side of a µG-VSC. The HGICB dc-dc converter is connected to the PV array works as MPPT controller and battery converter is used to regulate the power flow between dc and ac side of the system.

2.1 Photovoltaic (PV) System:

A solar cell is the most fundamental component of a photovoltaic (PV) system. The PV array is constructed by many series or parallel connected solar cells to obtain required current, voltage and high power. Each Solar cell is similar to a diode with a p-n junction formed by semiconductor material. When the junction absorbs light, it can produce currents by the photovoltaic effect.

The output power characteristic curves for the PV array at an insolation are shown in the Fig. 3. It can be seen that a maximum power point exists on each output power characteristic curve. The Fig: 4 shows the (I-V) and (P-V) characteristics of the PV array at different solar intensities. The equivalent circuit of a solar cell is the current source in parallel with a diode of a forward bias. The output terminals of the circuit are connected to the load. The current equation of the solar cell is given by:

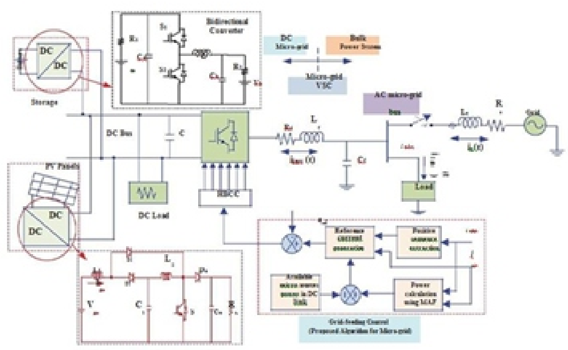

Figure 1: Hybrid energy conversion system

$I=I_{ph}-I_D-I_{sh}$

$I=I_{ph}-I_o[\exp(qV_D/nkT)]-(V_D/Rsh)$

Where: I_{ph} = Photo current (A) ID = Diode current (A) I_{sh} = Shunt current (A) VD = Voltage across diode (Volt) Io = Diode reverse saturation current (A) q = Electron charge = 1.6X10-19 (C) k = Boltzman constant = 1.38X10-23 (J/K) T = Cell temperature (K) Rs = series resistance (Ω) R_{sh} = shunt resistance (Ω).

The equivalent circuit of a solar cell is the current source in parallel with a diode of a forward bias. The output terminals of the circuit are connected to the load. The equivalent circuit of PV module is as shown in Fig 2

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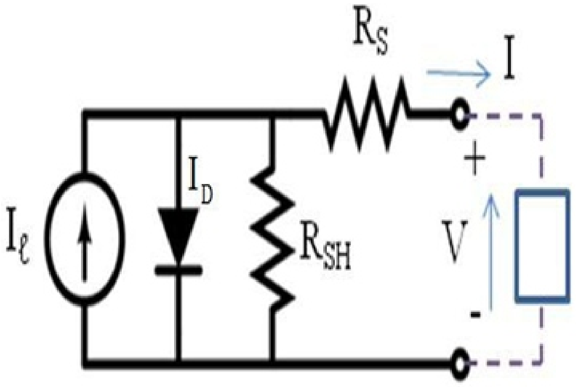

Fig 2: Equivalent circuit of PV Module.

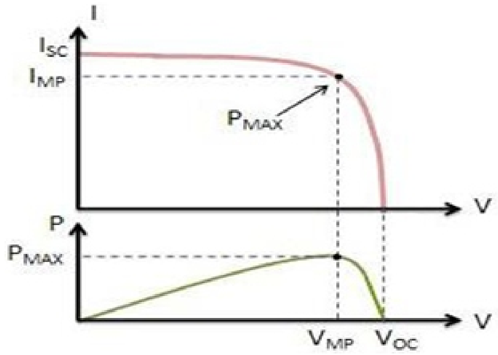

Fig 3: Output characteristics of PV Array.

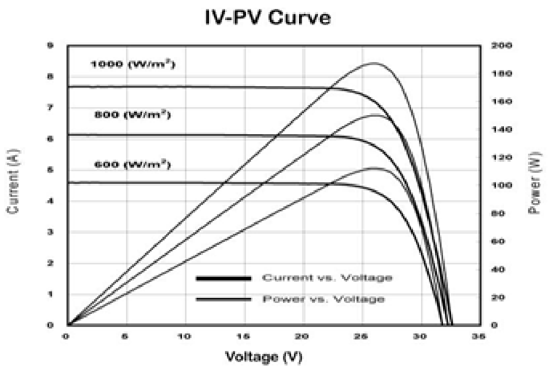

Fig 4: I-V and P-V Characteristics of PV Array at different solar intensities

2.2 Battery Energy Storage System:

Battery energy storage system (BESS) are includes batteries, control system and power electronic devices for conversion between alternating and direct current. The batteries convert electrical energy into chemical energy for storage. Batteries are charged and discharged using DC power, regulates the flow of power between batteries and the energy systems is done by a bi-directional power electronic devices.

Different types of batteries have various advantages and disadvantages in terms of power and energy capabilities, size, weight, and cost. The main types of battery energy storage technologies are: Lead-Acid, Nickel Cadmium, Sodium Sulfur, Nickel Metal Hydride and Lithium-Ion. Lead-Acid batteries, achieve high discharge rates by using deep-cycle batteries. Low energy density, non-environment friendly electrolyte and a relatively limited life-cycle are the limiting factors to its dominant use in urban renewable energy systems.

Overall, with low maintenance requirements, relatively low self-discharge rates, Lead-Acid batteries offer a competitive solution for energy storage applications. Sodium Sulfur batteries have high energy density, high efficiency of charge/discharge and long cycle life. Nickel Cadmium (NiCd) batteries achieve higher energy density, longer cycle life and low maintenance requirements than the Lead-Acid batteries. But, which include the toxic-heaviness of cadmium and higher self-discharge rates than Lead-Acid batteries.

Also, NiCd batteries may cost up to ten times more than a Lead-Acid battery, making it a very costly alternative. Nickel Metal Hydride (NiMH) is compact batteries and provides lightweight used in hybrid electric vehicles and tele-communication applications. NiMH batteries can substitute NiCd batteries in communications. They also provide equivalent cycle life characteristics, are environmentally friendly and can provide for an additional capacity ranging from 25 to 40%.

Lithium-Ion technology has the highest energy density amongst all types of batteries. They are currently used in cellular phones, computers, etc. and development of this technology is used in distributed energy storage applications. But, high cost and limited applications of technology. With the high rate of progress in development of lithium-ion technology, it has dominated the electronics market.

Because of the sizes it is used in small, medium and large scale renewable energy systems. During coupled operation, Changes in the wind and solar PV generation output will cause an immediate change in the BESS output and BESS must neutralize by quick changes in output power.Rate variation control (or ramp rate control) and it is applied for smoothing real power fluctuations from an associated coupled system.

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Allowable ramp rates are typically specified by the utility in kilowatts per minute (kW/min), and are a common feature of wind and solar power purchase agreements between utilities and independent power producers. The information is processed by the Battery Energy System controller estimates the state of charge (SOC) of each battery cell and capacity of each battery cell, and protects all the cells operate in the designed SOC range. The amount of electrochemical energy left in a battery is measured by SOC.

The SOC information is then used to control the charge-equalization. It is expressed as a percentage of the battery capacity. The electrochemical reaction inside batteries is very complicated and hard to model electrically in a reasonably accurate way. SOC is explained. SOC is mainly because of differences in chemical and electrical characteristics from manufacturing, aging, and ambient temperatures. When this SOC is left without any control, such as cell equalization, the energy storage capacity decreases severely.

Thus, charge equalization is necessary to minimize the mismatches across the battery and extend the battery life cycle. Generally, SOC is maintained between 30%-70% to get the longer life cycle for the battery. The technical and economic advantages of energy storage systems on a smaller scale are as follows:

1.Greater use of generally cleaner and more efficient energy sources.

2.Improvement of reliability and quality of electricity supply.

3.Provision of backup power for critical loads.

III. MAXIMUM POWER POINT TRACKING:

Maximum power point tracking technique is used to improve the efficiency of both the solar panel and wind turbine and they adjusted to operate at their point of maximum power. There are different techniques for maximum power point tracking (MPPT) methods have been developed and implemented. Few of the most popular techniques are: Perturb and Observe (hill climbing method), Incremental Conductance method, Fractional short circuit current, Fractional open circuit voltage, Neural networks, Fuzzy logic.

The MPPT Technique depends on the initial reference rotor speed for the wind turbine and an initial reference voltage for the photovoltaic array. The corresponding output powers of the two systems are measured. If this power does not correspond to their maximum powers, then their initial reference values are incremented or decremented by one step.

If this adjustment leads to an increase in their output powers then the next adjustment is made in the same direction and vice-versa. The above steps are repeated till the maximum power points of the wind turbine and photovoltaic array are reached. Fig. 3 shows the characteristic power curve for a PV array. The problem considered by MPPT techniques is to automatically find the voltage VMP or current IMP at which a PV array should operate to obtain the maximum power output PMAX under a given temperature and irradiance.

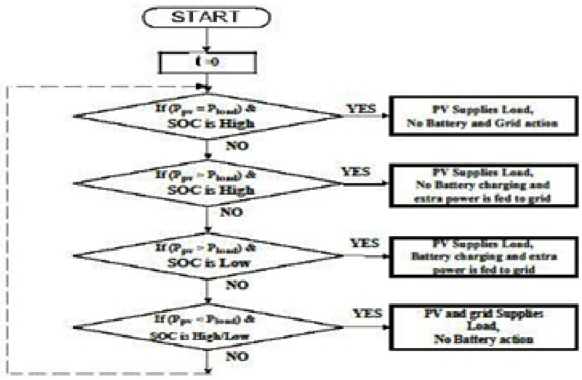

Fig 5: Flow Chart of power flow in hybrid system.

IV PROPOSED CONTROL FOR BATTERY CONVERTER:

If AC side of μG-VSC has constant power appliances (CPAs), in the small-signal sense, CPAs nature leads to negative incremental input-conductance which causes destabilization of the dc-link voltage. On the micro grid generation side, the inherent negative admittance dynamics of their controlled conversion stages challenges the dc-link voltage control and stability. This effect is more with reduced dc-link capacitance. Therefore, in both cases, fast and effective control and stabilization of the dc-link voltage is very crucial issue. To address this problem, many methods are reported in the literature like (i) by large DC link capacitance (ii) by adding passive resistances at various positions in DC LC filter (iii) by loop cancellation methods.

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4.1 Design steps for Compensators of BESS:

The effectiveness of proposed VRC's control algorithm is investigated and compared with the use of traditional ACMC. The flowchart for modes of operation of battery converter in grid feeding mode is shown in Fig. 5. The design guidelines for inner and outer loop compensators of ACMC are given below. The inner loop (current) gain can be written as:

Ti(s) = Gid(s) Ri Gci(s) Fm
The outer loop (voltage) gain can be written as:
$T_v(s) = G_{vd}(s)\, G_{cv}(s)\, (1 + G_{ci}(s))\, F_m$
and the overall loop gain therefore can be written as:
$T1(s) = T_s + T_v$

V. SIMULATION RESULTS:

Simulation study was carried out to analyze the dynamic performance of the proposed hybrid energy system design with the complete system is simulated using SIMULINK software. A PV/BESS hybrid system was considered. The system parameters used in the simulation study are presented below.

All the two energy sources are accurately modeled in SIMULINK so as to predict their actual characteristics. Tables1, 2 give the specification of the photovoltaic and fuel cell respectively used for the modeling and simulation.

Maximum irradiance level	1000W/m^2
Standard Operating Temperature	25^{0}C
Open Circuit Voltage of Each Module	37.1 V
MPPT Voltage	29.6V
Short Circuit Current of Each Module	8.28A
MPPT Current	7.6A
No. of cells in an each row	11
No. of cells in each column	2
No. of cells in an Array	22
Total PV Array Rating	9.9KW

Table 1: PV Array Specifications:

Battery Type	Nickel-Metal Hydrate
Rated Capacity	6.5Ah
Initial State of Charge	60%
Nominal Voltage	300

Table 2: Battery Specifications:

The proposed control strategies for PV hybrid generating system are developed and simulated using Matlab/SIMULINK under different solar insolation levels. In order to capture the transient response of the proposed control system, PV insolation is assumed to increase from 200 to 1000 W/m2 at 0.3 s, and decreases from 1000 to 200 W/m2 at 0.5 s. This abrupt increase or decrease is assumed in this work in order to test the robustness of the proposed control algorithm. As a result, the inductor current of the HGICB converter is varied to track the Maximum power accordingly and the power flow.The dynamic compensation performance of µG-VSC using proposed control algorithm with insolation change and non linear unbalanced load currents are shown in the Fig. 6.

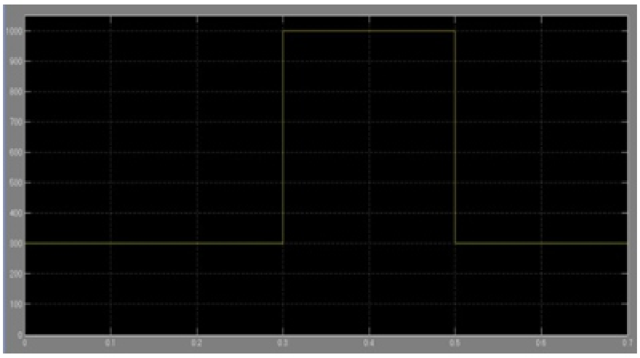

Fig 6(a): Irradiation.

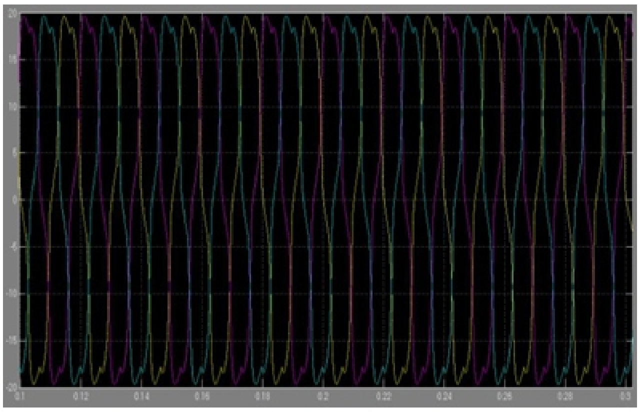

Fig 6(b): Load current.

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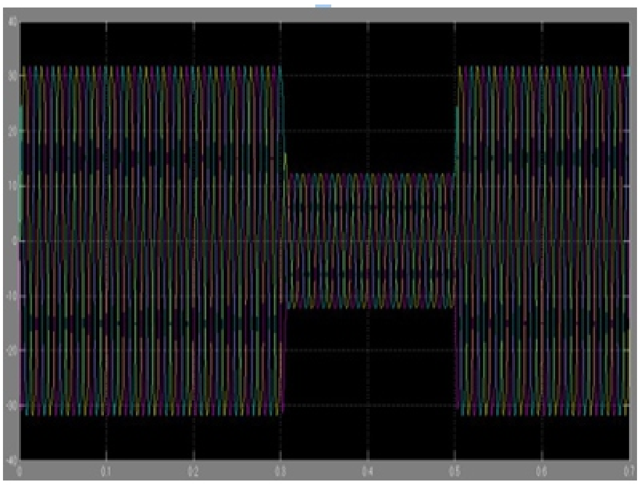

Fig 6(c): Grid currents.

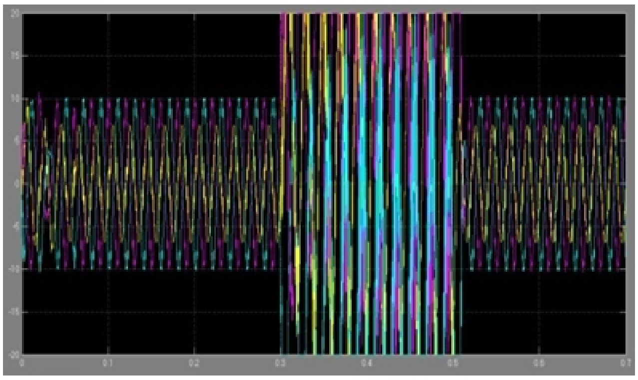

Fig 6(d): Inverter currents.

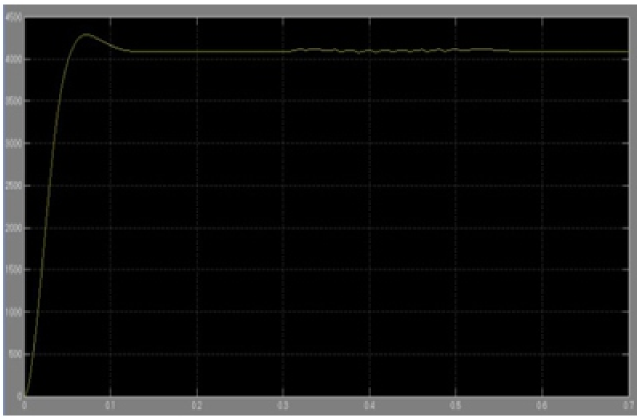

Fig 6(e): Real power of DC load

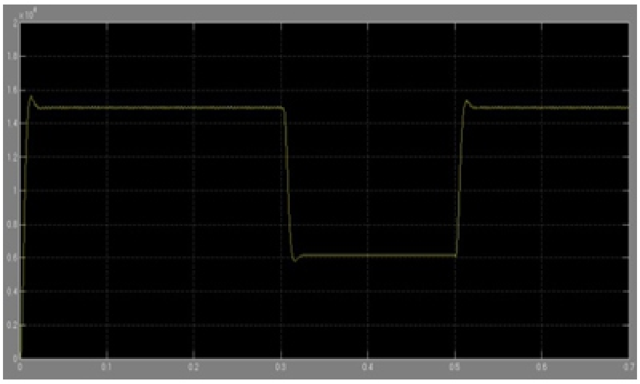

Fig 6(f): Real power of grid.

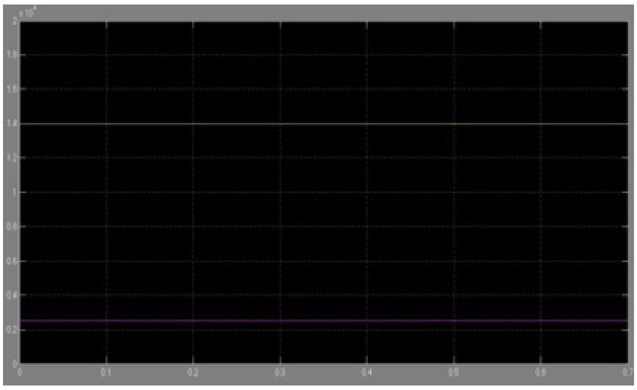

Fig 6(g): Real and Reactive Power of AC load

Fig 6: Simulation results using proposed control approach for micro grid side VSC

VI. CONCLUSIONS:

The performance of PV/Battery hybrid energy conversion system has been demonstrated with the application of modified instantaneous symmetrical components theory to µG-VSC proposed in this paper, an efficient control strategy is also proposed for battery converter to regulate the dc bus voltage tightly, under varying solar insolation and dc load conditions. HGICB converter topology is used to track the MPPT with high gain and less current ripple. The µG-VSC is able to inject the generated power into the grid along with harmonic and reactive power compensation for unbalanced non-linear load at the PCC simultaneously. The system works satisfactorily under dynamic conditions. The simulation results under a unbalanced non-linear load with current THD of 12% confirm that the µG-VSC can effectively inject the generated active power along maintains a sinusoidal and UPF current at the grid side with THD of 2.06%.

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